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# COST DATA ANALYSIS METHODOLOGY FOR DEFENSE NUCLEAR AGENCY LIFE CYCLE COST PROGRAMS

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## VOLUME I


MAJOR FRANKLIN L. GERTCHER

DEPARTMENT OF ECONOMICS


JULY 1984

## FINAL REPORT

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Department of English
U.S. Air Force Academy
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COST DATA ANALYSIS METHODOLOGY

FOR

DEFENSE NUCLEAR AGENCY LIFE CYCLE COST PROGRAMS

## ABSTRACT

This report contains two applications of cost data analysis. Volume I provides three cost models which were adapted for use with the Defense Nuclear Agency/ Multi-Agency Cooperative EMP Hardening Program. This program will result in a variety of designs for the protection of aircraft systems against nuclear electromagnetic pulse (EMP). Volume II presents three similar cost models which were adapted for use with the Defense Nuclear Agency Life Cycle Cost Experiment. This program will result in two alternative design concepts for the EMP protection of certain ground command and control communications facilities. Both volumes were given to the Defense Nuclear Agency in June 1984 as part of a funded research program.

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VOLUME I

COST DATA ANALYSIS METHODOLOGY

FOR

THE DEFENSE NUCLEAR AGENCY/MULTI-AGENCY COOPERATIVE

EMP HARDENING TECHNOLOGY PROGRAM

# I. INTRODUCTION

The Defense Nuclear Agency/Multi-Agency Cooperative EMP Hardening Technology Program will result in a variety of EMP protection designs and validation procedures for strategic aircraft systems. Using a C-130 "test bed" and certain laboratory facilities, the program will test alternative EMP protection concepts and designs. Technical and cost data will be generated, collected, and evaluated. These data will be used to plan EMP retrofit programs for existing aircraft, and to plan the EMP protection of new aircraft.

Technical data will include design guidelines, baseline tests, flight-certification of hardware, and test and validation procedures. These data will be made available to Air Force Special Project Offices in a documentation format used by the aircraft industry. The technical data base will be developed throughout the program, which is expected to continue through fiscal year 1988.

In a similar fashion, cost data will be generated, collected, and evaluated throughout the program. If sufficient detail is achieved in the cost data base, EMP protection costs can be extrapolated for a wide variety of aircraft systems.

A life cycle cost model should be set up to provide a methodology for collecting cost data. The model should include the following cost categories: program management, requirements definition, protection design, fabrication, installation and checkout, test and evaluation, and finally, protection operations and maintenance.

The life cycle cost model should contain three special features. First, it should separate costs that are unique to this particular program from costs that will be incurred in future aircraft EMP protection programs. This separation will permit future users of the data base to extract only those cost elements which pertain to their respective programs. Second, this model should permit detailed adjustments for inflation. Inflation indices can be used to update particular labor and

material costs. Third, learning curve analysis should be applied to labor-intensive activities. If EMP protection retrofit programs are implemented on a large scale, learning curve analysis would be appropriate to enhance the accuracy of forecasts for certain labor costs.

To achieve this, cost categories should be broken down into a number of sub-categories. For example, the requirements definition category should include sub-categories for: facility protection requirements, facility survey costs, requirements analysis, and surveillance and maintenance requirements. Each sub-category should include elements which indicate specific labor, materials, equipment, travel, and overhead charges. For example, the facility protection requirements sub-category includes elements for scientific and consultant manhours, design engineering manhours, pre-installation test and evaluation manhours, design quality control manhours, test and evaluation equipment costs, travel and design overhead costs.

At this point, it is also pertinent to consider how the cost data base might be used. In my judgement, program management, requirements definition, design, fabrication, and installation and checkout are essentially research and development (R&D) activities. As shown by W.J. Weida, an S-curve with cumulative R&D dollars spent as the dependent variable and time as the independent variable provides a highly accurate model for forecasting R&D expenditures per time period. The problem remains of what to do with the test and evaluation and the operations and maintenance cost data. Under certain conditions, we may be able to use all life cycle cost categories in a benefit-cost model.

The remainder of this paper provides details on a life cycle cost model, an S-curve R&D cost forecasting model, and a benefit-cost model for comparing alternative EMP protection designs. The life cycle cost model is based upon the work of Booz-Allen and Hamilton, Inc. and myself for the DNA Life Cycle Cost Experiment. The S-curve model can be developed from the cost data base with no limiting requirements. The benefit-cost model has one critical requirement: it must include some measure of the relative benefits of the alternative designs. If this measure is achieved, we can legitimately use a benefit-cost model to compare the alternative EMP protection designs. Without such a measure, legitimate life cycle cost comparisons cannot be made.

## II. LIFE CYCLE COST MODEL

The following proposed Life Cycle Cost Model is essentially a well-ordered data base. Its categories, sub-categories, and elements permit the identification of unique costs for the C-130 testbed program, detailed adjustments for inflation, and learning curve analysis for labor-intensive activities. It requires inputs of cost data from program managers, consultants, EMP protection contractors, test and evaluation contractors, and operations and maintenance agencies. Cost data should be submitted on a quarterly basis to a designated collection agency. Outputs of the model will include the cost data base, identification of cost drivers, and guidelines for future users. Finally, the model will provide a data base for a budget forecasting model and a benefit-cost model.

## LIFE CYCLE COST MODEL

| 1.0 PROGRAM MANAGEMENT | SCIENTIFIC & CONSULTANT | | MGT OVERHEAD | TRAVEL | | |
|---|---|---|---|---|---|---|
| | HRS | $/HR | | | | |
| 1.1 PROGRAM SURVEILLANCE | | | | | | |
| 1.2 DOCUMENTATION | | | | | | |
| 1.3 CONFIGURATION CONTROL | | | | | | |

| 2.0 REQUIREMENTS DEFINITION | S & C [1] | | DESIGN ENGIN. | | PRE-INS T & E [2] | | Q. C. [3] | | EQUIP T & E [2] | | RESEARCH OVERHEAD | | TRAVEL | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HRS | $/HR | HRS | $/HR | HRS | $/HR | HRS | $/HR | HRS | $/HR | HRS | $/HR | | | | | |
| 2.1 FACILITY PROTECTION REQUIREMENTS | | | | | | | | | | | | | | | | | |
| 2.2 FACILITY SURVEY COSTS | | | | | | | | | | | | | | | | | |
| 2.3 REQUIREMENTS ANALYSIS | | | | | | | | | | | | | | | | | |
| 2.4 PROTECTION SURVEILLANCE & MAINTENANCE REQUIREMENTS | | | | | | | | | | | | | | | | | |

NOTES: 1 = Scientific & Consultant
2 = Test & Evaluation
3 = Quality Control

| 3.0 PROTECTION DESIGN | S & C[1] | | DESIGN ENGIN. | | PRE-INS T & E[2] | | Q. C.[3] | | EQUIP T & E[2] | | DESIGN OVERHEAD | | TRAVEL | TOOLING DESIGN | | MFG. ENGIN. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HRS | $/HR | HRS | $/HR | HRS | $/HR | HRS | $/HR | HRS | $/HR | HRS | $/HR | | HRS | $/HR | HRS | $/HR |
| 3.1 SHIELDING | | | | | | | | | | | | | | | | | |
| 3.1.1 EXTERIOR | | | | | | | | | | | | | | | | | |
| 3.1.2 ENTRY | | | | | | | | | | | | | | | | | |
| 3.1.3 APERTURES | | | | | | | | | | | | | | | | | |
| 3.2 PENETRATIONS | | | | | | | | | | | | | | | | | |
| 3.2.1 POWER | | | | | | | | | | | | | | | | | |
| 3.2.2 SIGNAL | | | | | | | | | | | | | | | | | |
| 3.2.3 ANTENNA | | | | | | | | | | | | | | | | | |
| 3.2.4 GROUND | | | | | | | | | | | | | | | | | |
| 3.2.5 UTILITY | | | | | | | | | | | | | | | | | |
| 3.3 PROTECTION MAINTENANCE & SURVEILLANCE | | | | | | | | | | | | | | | | | |
| 3.3.1 SHIELDING | | | | | | | | | | | | | | | | | |
| 3.3.2 PENETRATIONS | | | | | | | | | | | | | | | | | |
| 3.4 DESIGN DATA PACKAGE | | | | | | | | | | | | | | | | | |

NOTES: 1 = Scientific & Consultant
2 = Test & Evaluation
3 = Quality Control

| 4.0 FABRICATION | MANUFACTURING | | | TOOLING | PLANT EQUIP. | PROD. Q. C. | | PROD. ENGIN. | | MFG. OVERHEAD |
|---|---|---|---|---|---|---|---|---|---|---|
| | HRS | $/HR | MATERIALS | | | HRS | $/HR | HRS | $/HR | |
| 4.1 SHIELDING | | | | | | | | | | |
| 4.1.1 EXTERIOR | | | | | | | | | | |
| 4.1.2 ENTRY | | | | | | | | | | |
| 4.1.3 APERTURES | | | | | | | | | | |
| 4.2 PENETRATIONS | | | | | | | | | | |
| 4.2.1 POWER | | | | | | | | | | |
| 4.2.2 SIGNAL | | | | | | | | | | |
| 4.2.3 ANTENNA | | | | | | | | | | |
| 4.2.4 GROUND | | | | | | | | | | |
| 4.2.5 UTILITY | | | | | | | | | | |
| 4.3 PROTECTION MAINTENANCE & SURVEILLANCE | | | | | | | | | | |
| 4.3.1 SHIELDING | | | | | | | | | | |
| 4.3.2 PENETRATIONS | | | | | | | | | | |

| 5.0 INSTALLATION & CHECKOUT | INSTAL. ENGIN. | | TEST & CHECKOUT | | ON-SITE MFG. MATERIALS | SITE MODS. | SPECIAL INSTALL. TOOLING | TRAVEL |
|---|---|---|---|---|---|---|---|---|
| | HRS | $/HR | HRS | $/HR | | | | |
| 5.1 SHIELDING | | | | | | | | |
| 5.1.1 EXTERIOR | | | | | | | | |
| 5.1.2 ENTRY | | | | | | | | |
| 5.1.3 APERTURES | | | | | | | | |
| 5.2 PENETRATIONS | | | | | | | | |
| 5.2.1 POWER | | | | | | | | |
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| 5.3 PROTECTION MAINTENANCE & SURVEILLANCE | | | | | | | | |
| 5.3.1 SHIELDING | | | | | | | | |
| 5.3.2 PENETRATIONS | | | | | | | | |
| 5.4 DATA/DOCUMENTATION | | | | | | | | |

| 6.0 TEST & EVALUATION | ENGINEERING | | TEST & EVAL. | | SPECIAL TEST EQUIP. | O & M OVERHEAD | TRAVEL |
|---|---|---|---|---|---|---|---|
| | HRS | $/HR | HRS | $/HR | | | |
| 6.1 PLANNING | | | | | | | |
| 6.2 CONDUCT | | | | | | | |
| 6.3 EVALUATION & REPORTS | | | | | | | |

| 7.0 OPERATIONS & MAINTENANCE | LABOR | | MATERIALS | SPECIAL TEST EQUIP. | OVERHEAD | |
|---|---|---|---|---|---|---|
| | HRS | $/HR | | | | |
| 7.1 OPERATIONS | | | | | | |
| 7.2 MANAGEMENT & CONTROL | | | | | | |
| 7.3 PROTECTION SURVEILLANCE | | | | | | |
| 7.4 MAINT./REPAIR | | | | | | |
| 7.5 DOCUMENTATION | | | | | | |

## III. S-CURVE R&D COST FORECASTING MODEL

Background

As indicated earlier, W.J. Weida has shown that an S-curve is a highly accurate form for forecasting R&D dollars spent per time period. If we realize that an S-curve is merely the cumulative form of a bell-curve (which may or may not be skewed) as shown in the following figure, a methodology for forecasting R&D costs per time period becomes apparent.

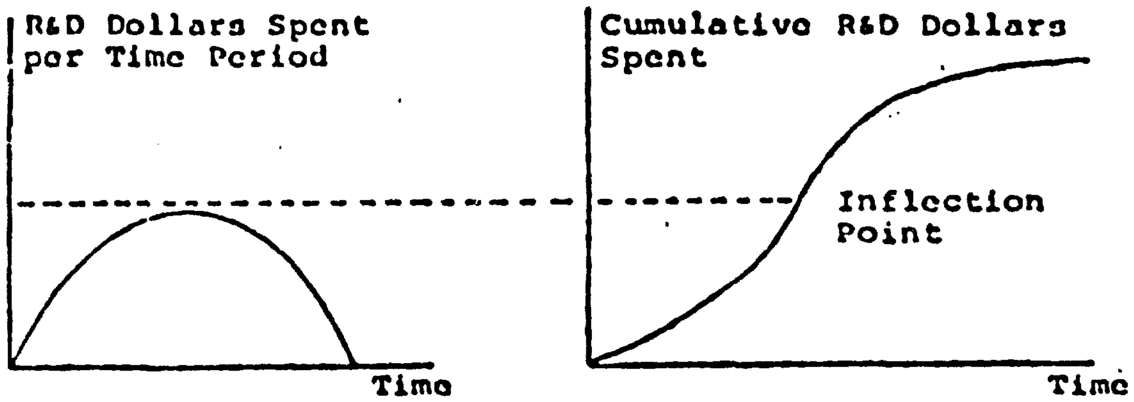


Figure 1: Derivation of the S-Curve

The S-curve can be fitted to historic cost data on similar R&D projects. Essentially, two curves are fitted to the data, one curve from time zero to the inflection point, and the other curve from the inflection point to the data point obtained at the end of the R&D effort. Both fitted curves follow a quadratic form.

$$y = a + b_1x + b_2x^2,$$

where a, $b_1$, and $b_2$ are coefficients estimated from a least squares regression.[2] Y and x are the dependent and independent variables, respectively. Before fitting the two curves, the data are normalized to percent cumulative dollars expended (y) and percent time expended (x). Normalization permits the use of the S-curve to forecast R&D costs for programs that differ in total dollars spent and time expended. The inflection point can easily be calculated by looking at the second differences of cost with respect to time, and the two curves can be joined at this point. Standard confidence interval techniques can be used to assess the

variation of actual R&D costs from forecasted costs. The forecast can be updated as data become available after a new R&D effort is started.

## Developing and Using the S-Curve

The general method for developing an S-curve from the C-130 testbed and cost data from other aircraft EMP protection programs can be described in a five-step procedure.

Step 1. R&D costs per time period from the C-130 testbed program and R&D costs per time period from other aircraft EMP retrofit programs should be gathered and recorded as a cumulative percentage of total R&D expenditure. These R&D expenditures include all generic cost data gathered in the program management, requirements definition, design, fabrication, and installation and checkout categories. Similarly, the amount of time over which the R&D effort for each program occurred should be determined and each succeeding time increment should be recorded as a cumulative percent of the total program time. This step has the effect of normalizing the data for all programs considered for the data base. See Figure 2.

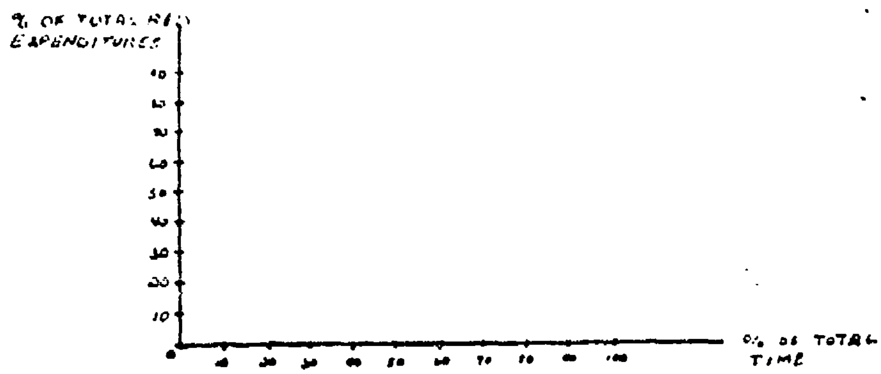


Figure 2: Expenditures vs. Time

Step 2. With the data arrayed in a normalized format and plotted on the axes of Figure 2, the budget expenditure pattern may be immediately checked for general conformity. This is accomplished by determining whether or not the cumulative expenditure curve follows the S-curve pattern established by Weida for all previous Department of Defense R&D projects, i.e., if aircraft EMP protection retrofit program cumulative budget expenditures follow the pattern shown in Figure 3, then these expenditures are in accordance with past R&D experience.

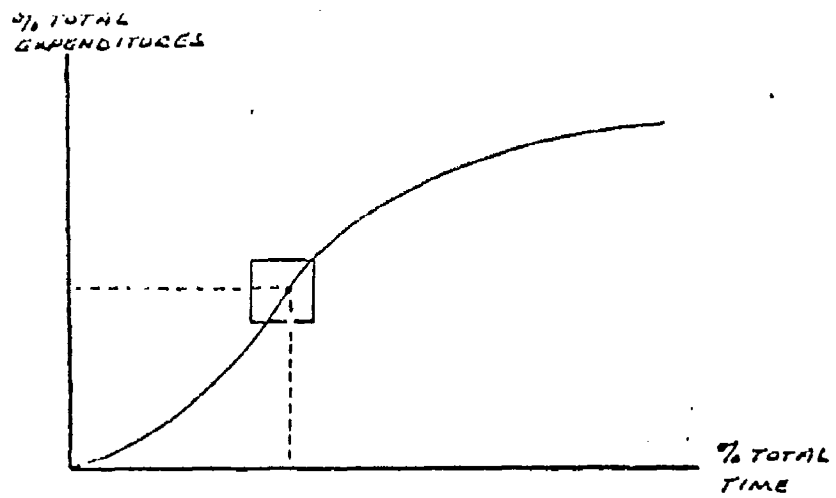


Figure 3: The General R&D S-Curve

According to Weida, the general curve can be described by the following equations:

$$Y = -0.0124 + 0.5376X + 1.396X^2 \text{ (Bottom Half)}$$

$$Y = -0.5345 + 3.1150X - 1.584X^2 \text{ (Top Half)}$$

The one-standard deviation ($1\sigma$) confidence interval about the inflection point was described by Weida as follows:

Mean: 0.562 (vertical axis), 0.462 (horizontal axis)

$\sigma_y$ = 0.05402 (vertical axis)

$\sigma_x$ = 0.07300 (horizontal axis)

If the expenditure pattern does not follow the general S-curve pattern, then alternative model specifications should be tried. For example, one might use a logarithmic form as a means to describe the cumulative expenditure pattern.

<u>Step 3.</u> Next, locate the largest incremental change in cumulative expenditures which is followed by two periods of decreasing cumulative expenditures. This increment is designated as the inflection point. The S-shaped curve is broken at this point and

the inflection point becomes the last data point in the first (or lower) curve and the first data point on the second (upper) curve. This common point allows the curves to be spliced again after curve fitting. The mean inflection point and $1\sigma$ values for the general S-curve were described earlier; however, past experience has shown a high degree of variability in the inflection point locations compared to the general S-curve.

Step 4. Equations for the lower and upper portions of the S-curve are developed using standard regression techniques. Again, data inputs include the normalized cumulative costs for the C-130 testbed program and the normalized cumulative costs from other aircraft EMP protection programs for which data are available. Particular care must be taken in this step to assure that the curve equations which are developed have dealt with the problems inherent in the use of time series data. Failure to correct the problem of autocorrelation will result in curve equations which are of little value and which will adversely affect the performance of the completed model. To correct this problem, the Cochran-Orcutt procedure for alleviating serial autocorrelation is usually applied.

Step 5. Once the curve equations have been developed from the budget data, two specific types of knowledge have been gained. First, the equation form which best fits the R&D budget data has now been determined. This is usually a quadratic form for both the upper and lower halves of the S-shaped curve. This specific curve form should be used with any actual expenditures when later attempts are made to forecast the R&D costs of future aircraft EMP protection programs. Second, equations expressing the subjective planning inherent in the R&D portion of an aircraft EMP protection program are now available for the upper and lower parts of the S-shaped curve. These equations can be used as guides during forecasting, thus providing a method of incorporating this subjective information into the final cost forecast for a future program.

## The S-Curve as a Forecasting Tool

The methodology developed in the previous section will result in an S-curve for forecasting R&D costs for future aircraft EMP protection programs.[1] It is appropriate at this point to convey

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[1] The methodology followed in this section is an abbreviated version of Weida's presentation in A General Technique of R&D Forecasting, U.S. Air Force Academy Technical Report 77-12, September, 1977.

the proper method for employing the S-curve as a management tool. The program manager should view the forecast as a non-threatening means of alerting managers to possible program difficulties and it should be presented not as a point estimate, but rather as a range of values within which the end cost of the program is likely to fall if the present courses of action are continued. For the purpose of this paper, three points along this possible range of cost will be identified as: (1) the best possible R&D cost, (2) the most likely R&D cost, and (3) the worst possible R&D cost. The best possible R&D cost occurs if the second half of the program follows exactly the R&D curve irrespective of the performance record established in the first half of the program. The most likely program cost is obtained if the second half of the program follows the course indicated by the R&D curve as updated by data made available from the first half of the aircraft EMP protection program being forecasted. The worst possible program cost would be indicated by the upper limit of the confidence interval around the updated forecast.

These three types of forecasts are shown in Figure 4. The details involved in forming each of these forecasts will now be discussed.

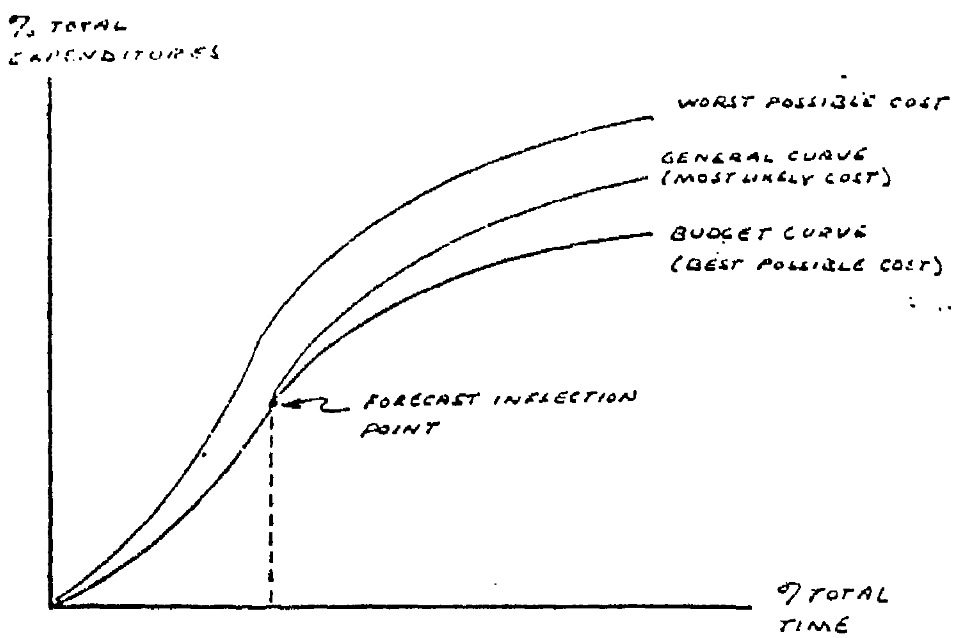


Figure 4: Three Possible Forecasts

## The Best Possible Cost

First, derive the two halves of the equation for the S-shaped curve in the manner previously outlined. This gives curve 1 of Figure 5, the aircraft EMP protection program R&D curve, or for the purpose of this discussion, the budget curve.

Assume now that the first data points concerning actual expenditure information have become available. These data points are first deflated by dividing the dollar figures by an appropriate inflation index. Studies have shown that the GNP Deflator is usually a good choice for this index.[2] The deflated figures are then converted to percentage figures by dividing by the latest deflated total program cost, and these percentage figures are plotted on the axis of Figure 2. This leads to the beginning of an "actuals" curve. These actuals may be used to forecast a new end cost for the program as follows:

(1) Derive a new lower half of the S-shaped curve by fitting the actuals to an equation of the form found to be appropriate for the budget data--in general, this will be a quadratic curve.

(2) Using this quadratic curve equation, insert the percent of total time figure for the budget curve inflection point (35% on Figure 5) to forecast a new inflection point, and then use other points on the X (time) axis to derive a new lower half for the S-shaped curve.

(3) Now take the equation which was developed for the top half of the budget curve and substitute the percent time and percent budget figures for the forecast inflection point into this equation to calculate a new intercept for the upper curve. This new intercept, along with the original slope figures from the budget curve, has the effect of "splicing" the equation

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[2] Brush, John S., "Study of Possible Improvements in the Accuracy of Aeronautical Economic Escalation Indices," unpublished paper, USAF Academy, Colorado, February 1976. Alternatively, indices for specific labor and materials can be found in: The Statistical Abstract of the United States, published annually by the U.S. Department of Commerce. Sections 12, 14, and 16 are of particular interest in the 1984 edition. Another source of specialized indices would be: Basic Economic Statistics, published monthly by the Bureau of Economic Statistics, Inc., Washington, D.C. Part 1 is of particular interest in the March 1984 edition.

developed from the first half actuals to the budget equation for the second half of the curve; all of which yields the new S-shaped curve 4 of Figure 5. In addition, this procedure allows the development of a forecast for the end cost of the project which is constrained by the planning and other subjective information inherent in the original budget curve.

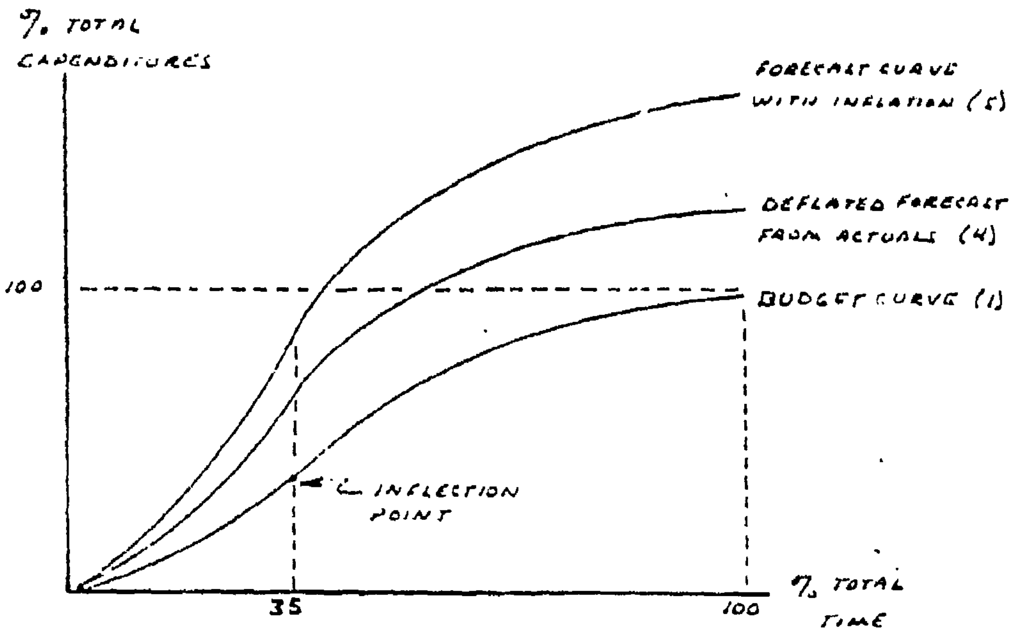



Figure 5: The Forecasting Process

(4) At this point, a program manager may take several different approaches. First, if he wants to learn the absolute figure for the final cost of the project, curve 4 may be modified by inclusion of inflation data. In this case, the forecast expenditure data of curve 4 would be multiplied by an inflation index to get a new curve which is labeled 5 in Figure 5. However, in doing this he should have in mind a concept of the errors inherent in any process such as the one just described.

Up to this point we have not mentioned, for the sake of simplicity, that there is an error involved in forecasting which should be expressed as a confidence interval around curve 4. The confidence band indicates that, with some given probability, one may expect the real value for any point on the line to fall somewhere within this particular interval. When the budget curve is

compared with the forecast curve, only one error, the standard error of the forecast, must be considered. This leads to the situation shown in Figure 6.

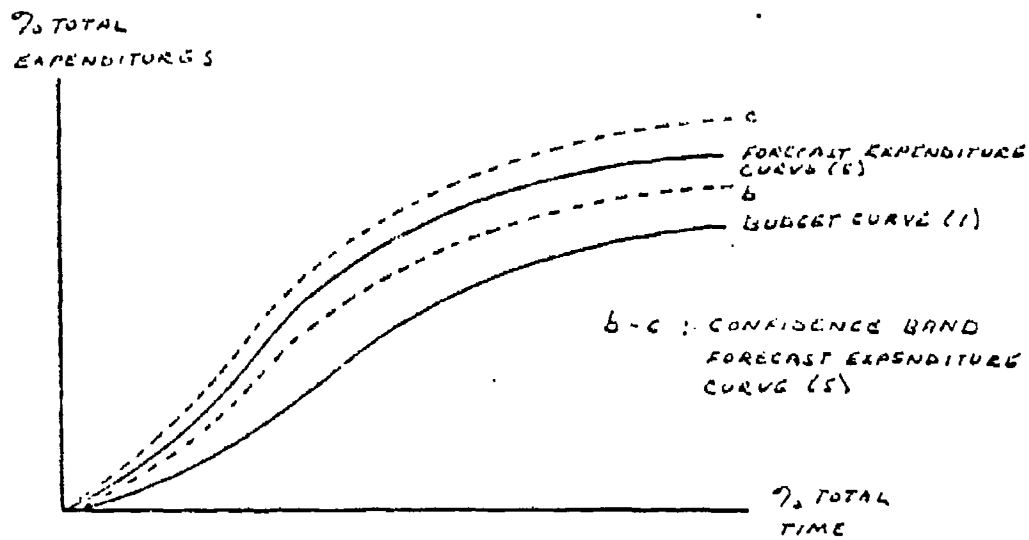



Figure 6: The Error of the Forecast

Here the confidence band indicates the possible range of values (from b to c) in which the true cost of the program is expected to fall, and similarly, the range of the size [from (1) to c] of the potential program overrun.

However, if one desires to compare the full cost, with inflation, of the project (Curve 5, Figure 5) with the full inflated cost of the budget, both the error of the forecast <u>and</u> the error involved in developing the inflation figures must be considered. This has the effect of greatly increasing the size of the confidence bands as is shown in Figure 7. The end result is that the ability to compare the final cost of the project with the budget cost is greatly impaired. As Figure 7 shows, in this case one could anticipate a tremendous overrun or an underrun [a - d] from the same data.

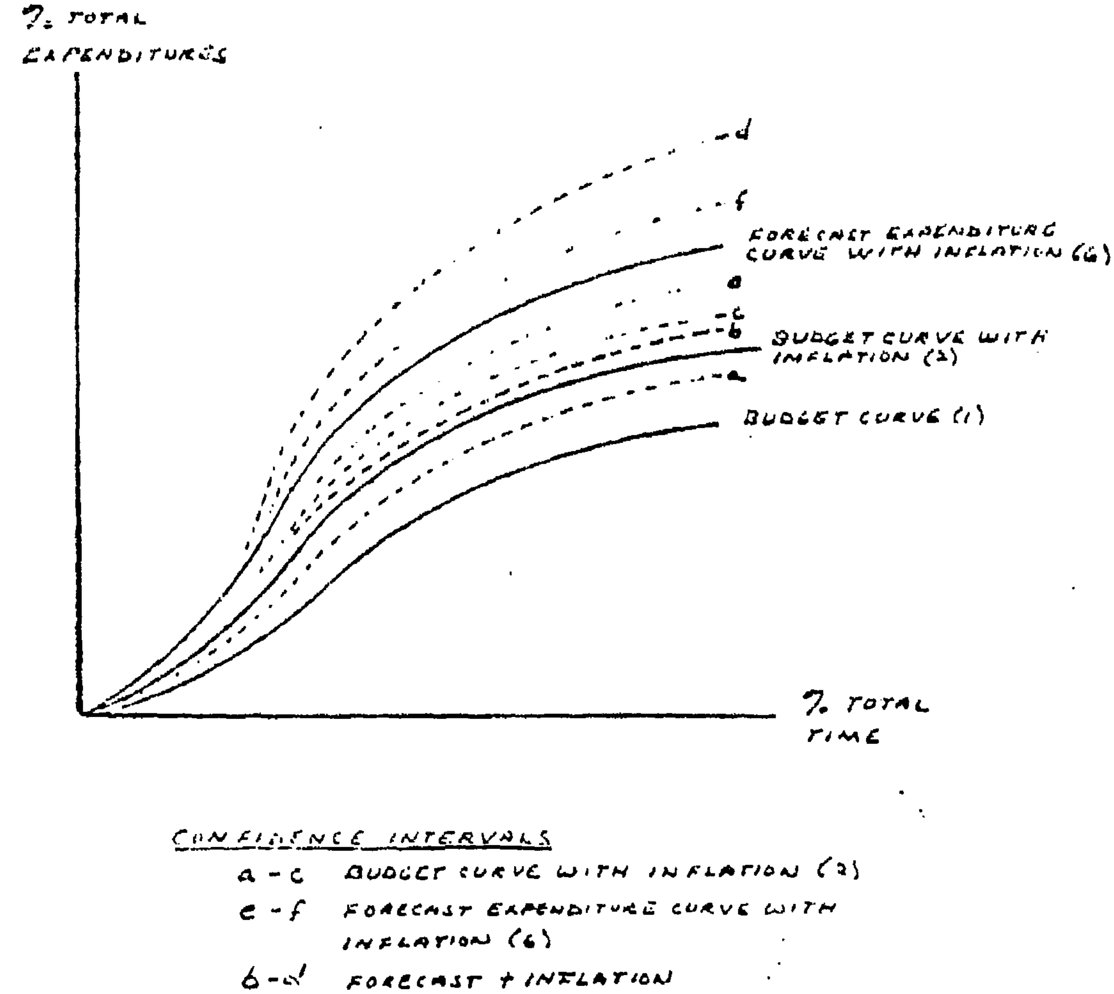



Figure 7: The Error of the Forecast and The Error of the Inflation Forecast

The lesson here is to compare figures in a manner which will minimize the errors involved in the comparison. In other words, the best picture of the status of a project may be gained by comparing the two curves shown in Figure 6. This comparison provides all of the information required for day-to-day management of the program. If a full end cost of the program is desired, this can be developed quickly by simple multiplication utilizing whatever inflation forecast is deemed appropriate at the time

that the information is required.

This does not mean, however, that the program manager should not use the actual inflation data when it is available. In this case, no errors of forecast are present because the actuals in both program cost and inflation rates are known. This makes it very easy to remove the effects of inflation to see how much of an overrun is actually attributable to other causes.

Figure 8 shows a case in which the deflated budget curve 1 is modified by the actual experienced inflation to derive curve 2. One may readily compare this curve with the contractor's inflated actuals (curve 3) to determine the actual extent of the overrun.

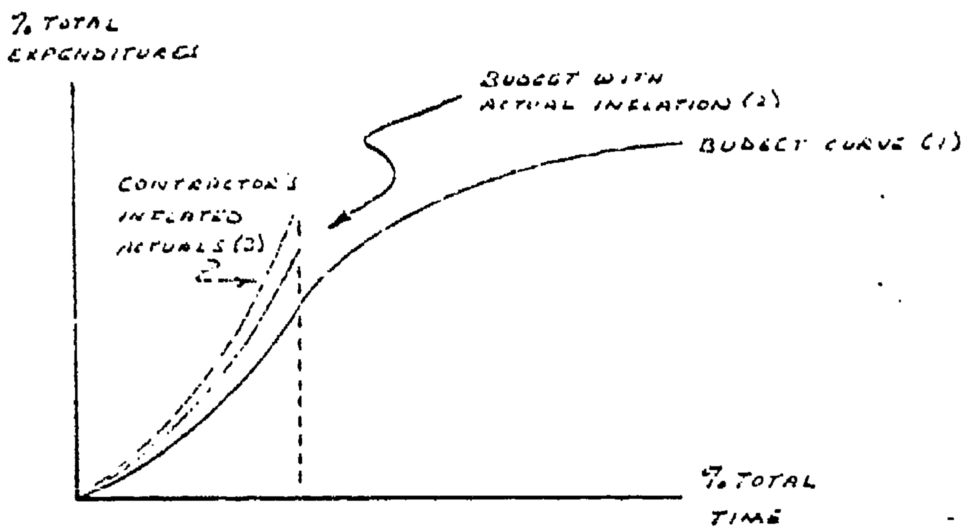



Figure 8: The Use of Actual Inflation Data

Another situation which this method of program monito will easily handle is the case of the schedule slippage or program extension. Of the two, the slippage is the most severe because it often occurs early in the project where it has a profound effect on costs. Assume once again the basic deflated budget curve shown in Figure 9 with an actual deflated expenditure curve as shown.

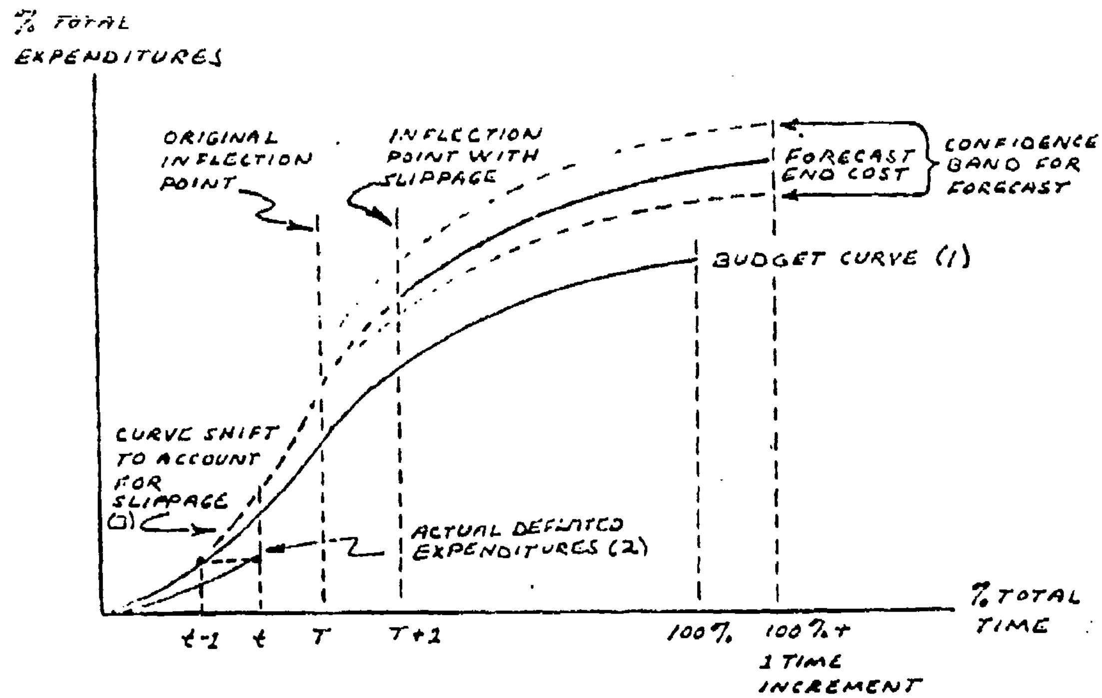



Figure 9: The Program Slippage Situation

It would appear upon initial inspection that the program is running slightly below the planned expenditures at time t. However, it is revealed that the R&D program is actually behind schedule, having only accomplished the number of milestones associated with time t-1. To compensate for this slippage, move curve 2 back one unit from t to t-1 so that the actual expenditures are now shown as curve 3 in their proper relationship with the budget curve. This is actually accomplished mathematically by calculating a new inflection point which will reflect the slippage in the schedule. This new point is derived from the equation for curve 2 by calculating the inflection point not at time T, the location of the original point, but rather at time T + 1, the location of the inflection point after slippage has occurred. This new inflection point becomes the intercept of the equation for the top half of the budget curve, and the time values which are used to forecast from the top half of the budget curve now start at the T + 1 increment (instead of T) and continue to the 100% + 1 increment (instead of the 100% increment).

The Most Likely Cost.

Forecasting the most likely cost proceeds in the same manner listed in the previous section up to the point at which a new inflection point is forecast. The actuals are converted to percentages and plotted in the same manner, and the curve form to plot these actuals is the same equation type selected to describe the bottom half of the general curve. At this point, however, the method of forecasting changes considerably.

Instead of merely splicing the top half of the general curve onto the new bottom curve, the bottom curve is actually mapped into the general curve framework. This is accomplished as follows:

(1) Using the deflated actuals from the program, fit whatever curve form is used in the bottom half of the general curve to these data and forecast a new value for cumulative expenditures at the inflection point. This new value is found by substituting the cumulative percent time figure which corresponds to the general curve inflection point into the new equation which was derived from the actuals.

(2) Take the new value for cumulative expenditures and let this value be equal to the cumulative percent of budget figure which is associated with the inflection point on the general curve.

(3) Using the relationships established in 1 and 2, the top half of the general curve may now be converted from cumulative percentage figures to forecast cumulative expenditures for the program being investigated.

This forecasting method has several advantages:

(1) The time over which the program is planned to run is taken as a given unless evidence to the contrary is discovered.

(2) The lower curve forecast is mapped into the general curve format, thereby creating a smooth S-shaped curve for the entire program. Simply splicing the curves as is done with the budget curve in the previous section will often create discontinuities in the curve.

(3) The forecast which is created in this method is based strictly on the assumption that expenditures in this particular program are proceeding in the same manner that all past programs have proceeded.

The Worst Possible Cost.

Developing the forecast for the worst possible cost is only a matter of slightly modifying the previous most likely cost forecast. A confidence interval for the most likely cost is calculated by standard statistical methods. The upper limit of this confidence band, based on whatever level of confidence was selected by the analyst, will give the cost figure that one can be X% certain will not be exceeded. Coupled with the most likely cost, this is an excellent management tool.

In summary, one may develop three possible forecasts from the S-shaped curve. The "spliced" curve forecast using the program budget curve reflects an expenditure of the lowest possible magnitude. For this expenditure to be realized, the program must run exactly as planned from the inflection point onward. This is a highly unlikely situation if any increased expenditures have been incurred early in the program. The most likely cost and its confidence band which extends to the upper confidence limit (or the worst possible cost) for the program are clearly the most realistic forecasts. This is because the method of mapping the new forecast for the bottom of the curve into the general curve format places the entire program in a more legitimate, historical perspective.

## IV. A BENEFIT-COST MODEL

Benefit-cost models provide an approach to solving problems of choice. In this case, the objective might be to choose the aircraft EMP protection design that provides the highest ratio of protection achieved per dollar spent. Other criteria besides a benefit-cost ratio might also be appropriate. For example, criteria such as the magnitude of first-year costs, budget limitations, uncertainty about future inflation or discount rates, and the degree of flexibility inherent in a particular design might be important for a particular program. A good benefit-cost model should permit the program manager to consider a broad range of decision criteria.

Benefits are often measured in dollars. In the case of EMP aircraft protection however, a dollar value cannot be placed upon the amount of protection achieved from a particular design. We therefore must resort to some non-monetary, generic measure of the amount of EMP protection achieved. As I indicated earlier, the legitimate application of a benefit-cost model is crucially dependent upon the availability of such a measure.

Keep in mind then, that for a particular EMP protection design, all dollar amounts are costs. Benefit-cost ratios are achieved by placing the measure of the amount of protection achieved in the numerator and the present value of life cycle costs in the denominator.

Let's consider the time value of money. A dollar paid today is not worth a dollar tomorrow because there is an opportunity cost that is determined by the amount of interest a dollar could have earned in an alternative investment. For example, a government tax dollar today is not worth a dollar tomorrow; it is worth more because it could be invested in the private sector and then be reclaimed with interest when tomorrow arrives. Also, tomorrow's dollar is not worth a dollar today. After all, the government could deposit 90 cents in a 10 percent investment and receive about one dollar one year from now. Many decision problems deal with situations in which amounts of money that exist in different time periods must be compared. This is the essence of the time value of money problem.

Consider the following tools for time value of money calculations.

(1) Future value, single amount:

$$S_n = S_o(1 + r)^n$$

where:

$S_n$ = Future value at the end of the nth period

$S_o$ = Present value at time zero

r = Interest (discount) rate expressed as a decimal

n = Number of periods

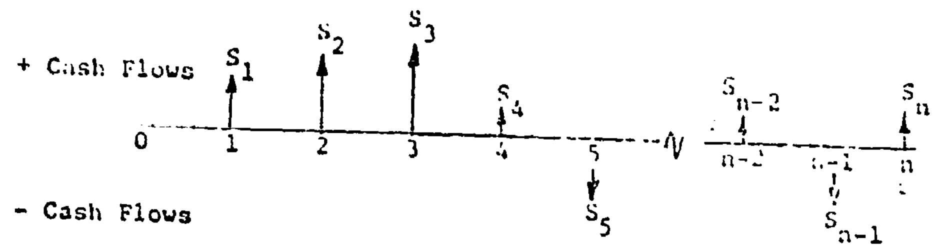
(2) Present value, single amount:

$$S_o = \frac{S_n}{(1 + r)^n}$$

where the definitions expressed above remain true.

(3) Present value, multiple cash amounts over time:

(a) Time line:

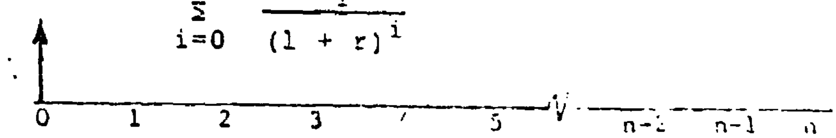



(b) The present value of these cash amounts, $S_1, S_2, \ldots, S_{n-1}, S_n$, can be expressed as:

$$\sum_{i=0}^{n} \frac{S_i}{(1 + r)^i} \qquad (3)$$

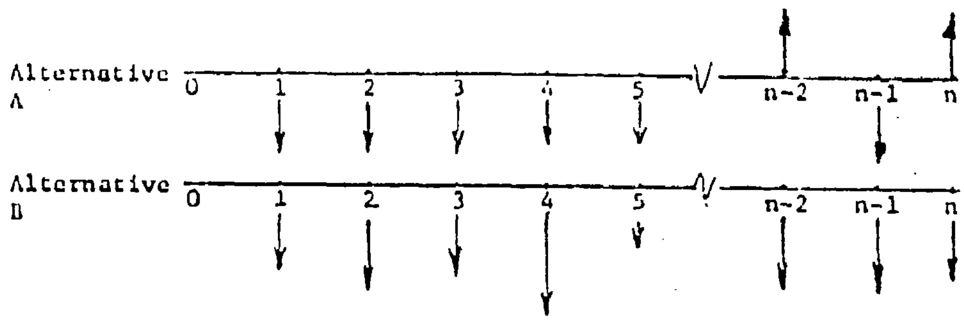
(c) Equation (3) converts the cash amounts over time as expressed on the time line in paragraph 3 above to:

$$\sum_{i=0}^{n} \frac{S_i}{(1 + r)^i}$$

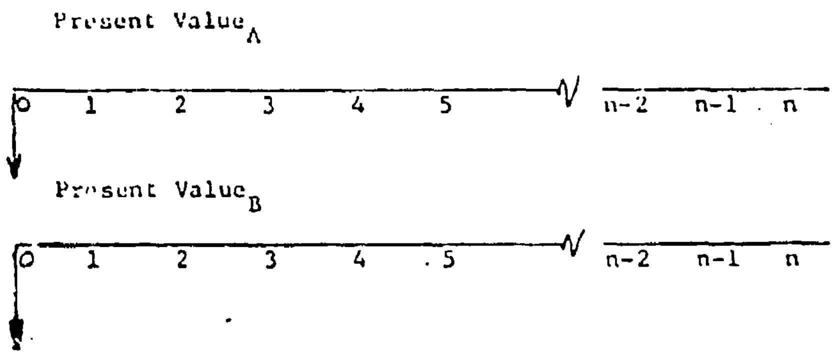


(4) If alternate aircraft EMP protection designs are to be compared, the cash amounts per time period for each alternative must be converted to sums which occur at a single point. For example.

(a)




(b) The costs which occur over the life cycle of Alternative A can be converted to a present value cost by using equation (3) above. A similar calculation would be accomplished for Alternative B. The results would be as depicted on the time lines shown below.




(5) Benefit-cost ratios for each alternative can now be calculated using the measure of the degree of protection achieved that I discussed earlier and the present value cost for the alternative in question. For example:

$$\text{Benefit-Cost Ratio} = \frac{\text{Measure of Protection for Alternative A}}{\text{Present Value Cost for Alternative A}}$$

(6) Let's consider Uniform Annual Amounts (sometimes referred to as Annuities) over a period of n years. A shorthand version of the present value cost equation can be used to simplify the analysis.

(a) Consider our present value equation with all of the $S_i$ equal to amount A:

$$P.V. = \text{(present value)} = \sum_{i=1}^{n} \frac{A}{(1+r)^i} \qquad (4)$$

(b) Since A is independent of period i, we can write:

$$P.V. = A \sum_{i=1}^{n} \frac{1}{(1+r)^i}$$

(c) Which can be shown to be equal to:

$$P.V. = A \frac{(1+r)^n - 1}{r(1+r)^n}$$

As a final note, it is sometimes useful to abbreviate as follows:

$$\text{pvf} = \text{present value factor} = \frac{1}{(1+r)^n}$$

$$\text{pvaf} = \text{present value of an annuity factor} = \frac{(1+r)^n - 1}{r(1+r)^n}$$

Now consider the interest (discount) rate used in government present value calculations. The choice of a discount rate is based on the premise that no government investment should be undertaken without explicitly considering the alternative use of the funds which it absorbs or displaces.

One way for the government to assure this is to adopt a discount rate policy which reflects private sector investment opportunities foregone. The discount rate reflects the preference for current and future money sacrifices that the public exhibits in non-government transactions. A 10 percent rate is considered to be the most representative overall rate at the present time. The government prescribed discount rate of 10 percent represents an estimate of the average rate of return on private investment before corporate taxes and after adjusting for

inflation. The cost analysis may include a test at other discount rates.

The economic lives of alternative aircraft EMP protection designs govern the time period to be covered by a program evaluation. Normally, these lives will approximate the life of the facility protected. The economic lives for the alternatives should be set, whenever possible, so that the alternatives yield benefits (EMP protection) for the same period of time. If this is not possible, the time period of the analysis should be based on the life of the asset with the shorter time period. In this case, the residual value of the asset with the longer economic life must be considered in computing the costs of that alternative.

Estimates for inflation in future years are often important in program evaluations. To detect the effect of changes in the purchasing power of the dollar, the program manager should consider both constant dollars (without inflation) and current dollars (with inflation) in analyzing and evaluating alternatives. To assure consistency, the first estimate of costs for each year of the planning period should be made in terms of constant dollars (that is, in terms of the general purchasing power of the dollar at the time of decision). If inflation is an important factor for the future, a second computation should be made in terms of current (inflated) dollars. When there is reason to believe that price levels will significantly affect the choice between alternatives, the indices cited earlier should be used. When including inflation for a cost which occurs more than 4 years beyond the present year, be aware of the uncertainty in making a valid economic forecast, and the fact that imputed values for inflation may change considerably.

To determine the change in real price (exclusive of the effect of discounting), calculate the effect of inflation in three distinct steps, as follows:

(1) Determine the constant dollar annual costs of the alternative.

(2) Inflate the annual cost using appropriate indices.

(3) Apply the discount rate to the escalated (current dollar) amount.

The present value equation presented earlier can also be adjusted for uncertainty with regard to the actual amounts of future costs. By substituting certainty equivalents for expected future costs, the model permits a decision maker to make an explicit tradeoff between the expected value of each cash amount and its associated uncertainty, or risk.[3]

The essential characteristics of the risk adjusted present value equation are as follows:

$$PV = \sum_{i=0}^{n} \frac{S_i^*}{(1 + r)^i}$$

where: PV = The present value at time zero of a series of risk-adjusted cash amounts which occur in the future for a particular program.

$r$ = An appropriate risk-free discount rate.[4]

$S_i^*$ = The risk-adjusted expected value of the cash amount for period i, i = 0, 1, 2, . . . n. This amount is commonly called a certainty equivalent.

For period i, a certainty equivalent ($S_i^*$) can be obtained by having the decision maker specify the amount of money that would make him indifferent between this certain amount and the expected

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[3] I use the terms "risk" and "uncertainty" interchangeably. For either term, I assume that future cash amounts have associated probability distributions. Risk (uncertainty) can be measured in terms of the degree of dispersion about the mean of the probability distribution. Also note that the probability distributions associated with future cash amounts are determined by the uncertainties inherent in the development, production, operation, and maintenance of a particular EMP protection design. As discussed earlier, factors for inflation due to changing resource costs can also be included. However, larger risks, such as the risk associated with the stability of the monetary system, are exogenous to the model.

[4] In some versions of the model, the discount rate is adjusted to include a risk premium for each period. This adjustment is used in lieu of the certainty equivalent adjustments to the expected cash amounts. Again, the degree of risk is determined solely by uncertainties inherent in the development and production of that particular weapon system.

cash amount with its associated risk. The magnitude of this certainty equivalent is determined by the decision maker's attitude toward the risk. There are undoubtedly some decision makers who would prefer risk and some who may be indifferent to risk, but conventional opinion among economists holds that the majority of decision makers involved with large sums of money tend to be risk-averse.

Thus, each $S_i^*$ is calculated by multiplying the expected cash amount for period i by a certainty equivalent factor which is based upon the decision maker's attitude toward risk. The certainty equivalent factor for a cost must be a number greater than one, i.e., the present value cost is made larger.

## V. SUMMARY AND RECOMMENDATIONS

The C-130 testbed program will generate valuable cost data which can be used to develop planning models for future aircraft EMP protection programs. In this paper, I have briefly disussed a life cycle cost model, presented an S-curve model for R&D cost forecasting, and finally, discussed a possible benefit-cost model for comparing alternative aircraft EMP protection designs. The S-curve model can be developed from the life cycle cost data base with no limiting requirements. The benefit-cost model cannot be developed unless it includes some generic measure of the degree of protection achieved by the alternate EMP protection designs.

The life cycle cost model should be coordinated with all agencies involved in the C-130 testbed program. Changes should be made, if appropriate, and cost data should be collected. Additional cost data on previous aircraft EMP protection programs should also be gathered, and as accurately as possible, integrated into the model. Please note that the cost data and milestones for each program will be kept separate within the model.

I recommend that we continue to explore possible uses for the life cycle cost data base. The S-curve model and the benefit-cost model appear to be useful tools for future EMP-protection planners. Other models are possible. Given the amount of attention focused on defense budgets and the relatively large expenditures envisioned for a large-scale aircraft EMP protection effort, it would appear worthwhile to provide EMP protection planners with appropriate models for conscientious and accurate budget forecasts.

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